Multispace Design Model as Framework for Design Science towards Integration of Design

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Abstract
While the design by the 20th century brought people's life rich, it also produced many negative legacies. In order to solve these problems produced by subdivision of a design, the new viewpoint for the integration of each subdivided design is required. Firstly, this paper summarizes the context of conventional design which results in subdivision of a design. Secondly, this paper describes a framework for design science as the new viewpoint for the integration of each subdivided design. Moreover, this paper describes the multispace design model as a framework of design theory and design reasoning. Finally, this paper introduces the study on the integration of design based on the framework for design science and the view of the design in the 21st century.

1. Introduction
Since the industrial revolution began in the 18th century, people’s lives have been enriched by numerous highly functional artificial products. Pre-21st century design for these products was subdivided and streamlined through a process involving mechanization, specialization, and professionalization as well as through scientific and technological advances. However, this design process also promoted negative legacies. Mass production and consumption have endangered lives and created problems such as resource and energy crises, global environmental issues, and safety issues that may trigger accidents at large-scale facilities. Hence, the subdivided design has to wrestle with these problems in solidarity.

Hence, it has been committed to addressing these issues by integrating subdivided design. To this end, design science that is the common basis of a subdivided design is indispensable. Herein this paper describes the necessity of constructing the framework for design science, which combines subdivided design, and proposes the multispace design model to realize design integration. Additionally, a vision for design in the future is presented.

2. Problems Left by Pre-21st Century Design
Pre-21st century design drove the high performance and functionality of artificial products by producing complex products on a mass-scale. Although this improved people’s material wealth, it also caused numerous global environmental issues, including resource and energy crises, global warming, acid rain, and desertification as well as caused large-scale accidents at nuclear power plants and oil drilling facilities. Mass scale-ups and complexity are still advancing, further escalating the extent of the damage caused by these issues. Hence, pre-21st century design produced highly functional artificial products through subdivision, but left negative legacies due to difficulties in integrating subdivided design.

As society enters the 21st century, many people are able to obtain material comforts and are demanding riches of life in terms of mental satisfaction. Compared to material comfort, mental satisfaction strongly depends on individual values. Thus, future design must accommodate the diversity in individual values. Additionally, because the rapid advances in information technology allow people to easily obtain information, individual values are likely to change in accordance with the obtained information. Therefore, design should address the diversity in values between individuals (spatial diversity) as well as variances in time (temporal diversity). Furthermore, the diversity of people who use artificial products as well as the circumstances these products are used should be evaluated. Recently, an increasing number of artificial products have been used in extraordinary circumstances such as space, deep sea, and inside the human body. These vastly different environments require that design is accurately conducted by considering artificial products in such extraordinary circumstances.

Hence, 21st century design has diversified in many aspects, and individual design methodologies, which were developed according to the subdivision of pre-21st century design, makes it difficult to address the current situation.

3. Context of Design
In this chapter, the context of pre-21st century design, which caused many issues, is discussed (Fig.1). During the industrial revolution, the mechanization of designing artificial products, which was introduced by placing priority on enhancing efficiency in manufacturing, was achieved. Although many products were realized, the market was flooded with unattractive and low quality products. In the 19th century, a new design concept was initiated to address issues with mechanization. Design for artificial products was specialized into two categories: engineering design (ED) and industrial design (ID). In ED, design was conducted for the artificial products themselves to materialize function and performance, whereas ID considered the relationship between artificial products and circumstances such as users and usage environment. Furthermore, ED and ID were independently developed
During the 20th century, their professionalization was advanced; ED was supported by the emergence of systems engineering, whereas ID was developed through the foundation of Bauhaus (a German architecture and design school).

Since then, ED and ID have undergone further specialization and professionalization, resulting in the subdivision of design. Examples include design by location or a specific part such as the interior or exterior design of an automobile and a specialized area such as electronics or mechanical design. These subdivisions have many advantages for designing artificial products, but difficulties, including sharing design information in collaborative designs, have also risen. These difficulties have led to the aforementioned negative legacies.

4. Framework for Design Science

This chapter describes a framework for design science to integrate subdivided design with design theory and design reasoning, which are the building block of design sciences. Design science is an academic discipline that theoretically explains design as a human’s creative activity and extends beyond each of various existing subdivided design fields such as product design and urban/architectural design [1]. To date, design science examines design methods and methodologies, which depend on the object of each study. However, studies on design theory and methodologies that are independent of the object of study have been rarely conducted.

The general design theory [2, 3] developed by Yoshikawa and colleagues consists of an important basis to study design theory and methodologies. Pursuing further studies beyond Yoshikawa’s effort is imperative to develop a framework of design science. A framework of design science discussed herein is comprised of design knowledge and designing. Design knowledge consists of general objective knowledge and special subjective knowledge. Designing contains four layers: design practice, design method, design methodology, and design theory (Fig.2-a). Hereupon, designing is defined as an action to be conducted based on design knowledge. In the four layer scheme, specialty and dependence on the design object increase as the layer proceeds from a lower layer to a higher layer. In contrast, generality and abstractness increase as the design proceeds from the upper layer to the lower layer.

With regard to design theory, which is situated in the lowest layer of this framework, the multispace design model is applicable to this framework. The multispace design model [4-6] aims to comprehensively deal with design, and is comprised of thinking space and knowledge space (Fig.2-b). Thinking space includes a reasoning model for four types of spaces and inter-spaces: value space, meaning space, state space, and attribute space. Value space consists of numerous scopes such as social, cultural, and individual values. Meaning space is comprised of function and image. State space includes dynamical, electrical, and chemical characteristics, which depend on the circumstance. Attribute space consists of the characteristics of the design object, and is independent of the circumstance. Value space and meaning space are considered psychological spaces, whereas state space and attribute space are physical spaces. Knowledge space is comprised of objective knowledge and subjective knowledge. Objective knowledge holds generalities such as theories and methodologies, including physical laws in natural science, social sciences, and humanities. In contrast, subjective knowledge contains specialties that depend on individual contexts. Knowledge space is the basis for identifying intra-space and inter-space.
models in thinking space.

Based on these knowledges, designers and engineers conduct reasoning in intra-space and inter-space models. Deduction and abduction coexist in between value and meaning spaces and in between state and attribute spaces:

Deduction in psychological space:  \( K \cup Am \vdash Av \)  
Abduction in psychological space:  \( K \cup Av \vdash Am \)  
Deduction in physical space:  \( K \cup As \vdash Aa \)  
Abduction in physical space:  \( K \cup Aa \vdash As \)  

where \( K \) is knowledge, \( Av \) is a value concept set, \( Am \) is a meaning concept set, \( As \) is a state concept set, \( Aa \) is a attribute concept set, \( d \) is an inference rule of deduction, and \( a \) is an inference rule of abduction. Additionally, deduction and abduction coexist in between “psychological space” and “physical space”:

\[
\text{Deduction: } K \cup Aph \vdash Aps \quad \text{(5)}
\]
\[
\text{Abduction: } K \cup Aps \vdash Aph \quad \text{(6)}
\]

where \( Aph \) is an abstract concept set in “physical space” and \( Aps \) is that in “psychological space”.

Design reasoning is a process that corresponds to each of three classes and is roughly divided into: design problem analysis, idea generation, and idea evaluation. As shown in Fig. 2-c, induction, abduction, and deduction are often used for design problem analysis, idea generation, and idea evaluation, respectively.

In design, design problem analysis for a given task is initially performed based on induction. Then an idea as a candidate design solution is generated based on abduction. The obtained ideas are then evaluated based on deduction using the results of design problem analysis. The idea satisfying the evaluation becomes the design solution. If none of the ideas satisfy the evaluation, then design reasoning is repeated.

![Fig.2 Multispace Design Model as Framework of Design Science](image-url)
5. Integration of Design

In this chapter, our past studies to integrate design are reported, and the integration of design based on the framework for design science is discussed. In our studies on internal-focus and external-focus design [5, 6], ED and ID are perceived based on the framework for design science (Fig.3). ED is interpreted as internal-focus design performed by emphasizing the internal system. ID is conducted so that external-focus design focuses on the relationship with the external system. Thus, integration follows the overview of the design context from the perspective of internal-focus and external-focus design (Fig.1). Additionally, our studies, which analyzed design characteristics [7], compared various ED and ID studies by examining papers published by academic societies for engineering design that mainly cover ED as well as societies for design that mainly cover ID from the viewpoint of the multispace design model as a framework for design theory. Our qualitative study indicates that studies focusing on value space and meaning space are important for the former societies, whereas those focusing on state space are predominant for the latter.

Furthermore, our studies on the multispace design model [8, 9] have defined evaluation items for various design analysis methods and design generation methods from the perspective of the multispace design model. Moreover, we have established a classification system for these methods based on the results obtained from cluster analysis by setting evaluation items as variables. Combination matrices that unite design analysis methods with design generation methods have been prepared, and an idea generation support technique for the early process of design has been proposed by integrating these matrices with the classification system. This technique has been upgraded to an integrated design method to comprehensively support all design processes from the beginning to the end by introducing a factor selection method and a technique to visualize the layer structure of design as well as the relationship between design elements using QFD (Quality Function Deployment) and ISM (Interpretive Structural Modeling).

This upgraded technique should realize the effects explained below via design integration studies based on the aforementioned design science framework. First, establishing a common basis for subdivided design has realized sharing and collaboration of design information. Next, clarifying existing design knowledge has allowed intelligence missing in existing studies to be extracted. These measures should advance design science and promote design integration itself. Finally, as the integration of design is realized, initiatives for overall design and philosophy, which have been lost, may be revived against the current reality where subdivided design is embedded into commercial systems based on economics. As the 21st century unfolds, it will be important to continue design studies based on new viewpoints that can comprehensively address various designs and to create new intelligence capable of solving the remaining issues.

6. Conclusions

Herein current issues left by pre-21st century design as well as the design context that led to these issues are reviewed. In addition to discussing the necessity for a framework of design science capable of integrating each subdivided design, a framework for design science is presented along with the multispace design model. Several examples of integration studies for design based on design science are reported and the future vision for studying design has been presented.

References